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What is the Economic Meaning of the Precautionary Principle?

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1. Introduction

The Precautionary Principle ("PP") defines a new standard of risk management when the very existence of risk is subject to some scientific uncertainty. It was introduced at the 1992 Rio Conference in its Article 15. It states that *"where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"*. Similar definitions exist in various international treaties: the 1992 Convention on Climate Change, the 1992 Convention on Biological Diversity, the Maastricht Treaty, and the 2000 Protocol on Biosafety.

The general formulation above is both the strength and the weakness of the PP. It is its strength since it has a high degree of generality. It may be used in principle in all environmental protection or health safety issues that present high conditions of uncertainty, as in the recent "mad cow" crisis for instance. It is its weakness since it has no practical content and offers little guidance for conceiving regulatory policies.

A direct consequence of this common formulation is the risk of diverging interpretations. For example, the PP has been a matter of dispute between the European Union and the United States in trade relations. In a recent report (CEC, 2000), the European Commission explicitly recognizes the difficulty of interpreting the PP. The first sentence of the report states: *"The issue of when and how to use the Precautionary Principle, both within the European Union and internationally, is giving rise to much debate, and to mixed, and sometimes contradictory views."* Facing the need for a better understanding of the PP, the debate recently has often moved to the philosophical arena. A typical question is the place of "sound science" in our society.

In this paper, we argue that economic science may provide a sensible and practical interpretation of the PP. For a long time, economists have investigated the links between irreversibility, risk and the prospect of increasing information over time. It has triggered an important research field in finance and investment theory. Importantly, those ideas have been recently incorporated into broader issues related to risk management and environment policy. A normative economic basis for the PP has been put forward (Gollier, Jullien and Treich, 2000). The cost-effectiveness of precautionary policies has been examined for the climate-change problem.

However, we will also argue that the PP should at the same time be enforced at the political and judicial level. Indeed precautionary policies may not emerge spontaneously in competitive industries, such as in the energy or the agri-business sectors. Also, the presence of

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scientific uncertainty may favor opportunistic behaviors through the complex channels of risk regulatory decision-making. The issue will then be to design the PP to reduce the opportunism of some agents in situations of incomplete information or imperfect monitoring. Importantly, regulatory policies must also be designed to be acceptable to the public. This raises fundamental political economies issues that we will evoke in the last part of the paper.

2. Interpreting the precautionary principle

In this section, we will present some of the challenges raised by the PP to policy-makers. We shall stress some typical characteristics of new technological or environmental risks that complicate risk-sharing and regulatory decision-making.

2.1. Decision-making under scientific uncertainty

The PP addresses the difficult question of how society should manage hazards whose characteristics are unknown. Today, examples abound of risks which are imperfectly known: species extinction, global warming, waste hazards, electromagnetic fields, cellular phones, transgenic food; the list could go on. Take the recent "mad cow" affair, for instance. Scientists do not know how "mad cows" became infected or how long humans incubate the disease. As a result, current estimates of human victims in the U.K. over the next two decades vary from 100 to more than 100,000.

Those risks may not be easily addressed by standard prevention or insurance activities. There are obvious reasons for this. The traditional foundations of the insurance industry rely on accurate measures of risks and need reliable actuarial tables. Also, the law of large numbers does not operate well, since risks may have catastrophic consequences. For the sake of concreteness, take the climate-change problem as an example. Prospects for diversifying risks are limited: there is on earth one climate and the risk may affect billions of people in the same period of time. The possibilities of diversifying the risks over time are limited as well: the change in climatic conditions, if it happens, will likely be lasting. Finally, the damages may arise in a time-span of several decades or centuries so that it is not technically possible to organize their risk-sharing.

In addition, the analysis of efficient policies to deal with those imperfectly known risks is complicated by several factors. Typically, damages are generated by an accumulation process in some medium (air, water, soil, body). As a result, this process of accumulation can respond only slowly to the change in the annual rate of emission/consumption, so that one cannot readily reverse or mitigate physical degradation other than by letting the natural rate of decay operate. Moreover, there exist more radical types of irreversible processes. For instance the brain disease that may result from eating "mad cows" is irreversible. The loss of some animal species due to climate change or the diffusion of some genetically modified species may also be irreversible. Another kind of irreversibility comes from the inertia linked to the socio-economic system, e.g. it takes time to develop low-cost substitutes for the pollutants.

Importantly, there is another typical feature that characterizes these new technological or environmental risks: the improvement of knowledge over time. Indeed, while at first uncertainty may loom very large, there is high potential for rapid resolution of uncertainty. There is ongoing research on these new risks. Also, one may learn by observing some early consequences of the risk. Acknowledging this leads to recognizing the importance of defining the appropriate timing in prevention efforts. The cost of being wrong in either direction is high and there are large potential gains from flexibility in prevention investments. The Loi Barnier

in French law (95–101, 1995) emphasizes this point in its formulation of the PP: *"The lack of certainty, in the present state of scientific and technological knowledge, should not lead to the postponement of effective and proportionate measures aimed at preventing threats of serious and irreversible damages to the environment, at an acceptable cost"* (translated from the French). The main message of the PP is conceptually clear: scientific progress does not justify the delay of measures preventing environmental degradation.

2.2. Act-then-learn strategies

According to the PP, prevention measures should be initiated before scientific evidence is made available. Politically, this is a new and challenging idea. Under the usual timing, decisions are taken under conditions of sufficient, or, say, supporting knowledge. There is a basic rationale for this, simply that it makes sense to adapt prevention efforts to the nature and the severity of the risk. This is typically a "wait-and-see" or "learn-then-act" strategy. Instead, the PP is a tribute in favor of "act-then-learn" strategies.

To understand why "act-then-learn" strategies may be economically efficient, one has first to recognize that the perception of risks faced by society has profoundly changed in the last two decades. The recent history of risk management has indeed been sullied by several dramas generated by faulty management of human-induced problems, such as the development of cancers from asbestos or the drama of contaminated blood transmitting HIV.

As a result, many politicians and eco-activists favor an extreme interpretation of the PP. Everything should be done to reduce the risk to its lowest possible level. For example, Greenpeace asserts *"Do not admit a substance unless you have proof that it will do no harm to the environment."* This interpretation tends to make "zero risk", if technically feasible, become the norm for potential risk management policies.

This interpretation is not compatible with economic efficiency. It would virtually eliminate innovation in our society (Gollier, 2001). The last two centuries of dramatic innovation-driven growth call for a rejection of this extremist approach. For a risk to be economically desirable, the benefit to society should dominate the cost it generates. The society has to balance the risk of a potential catastrophe against the risk of over-cautious policies that would inhibit progress in our society.

Interestingly, this trade-off was recognized in the presidential conclusion to the European Council Meeting in Nice in December 2000. The report states that *"... the measures adopted presuppose examination of the benefits and the costs of action and inaction"*. A little later this report even emphasizes that *"... decisions taken in accordance with the Precautionary Principle should be reviewed in the light of developments in scientific knowledge. To that end the impact of such decisions should be monitored and additional research conducted in order to reduce the level of uncertainty."*

According to this interpretation, the PP thus underlies the need to identify optimal short-term strategies that should permit a response to new information with mid-course corrections. The challenge is thus to define and implement the optimal action today, given that uncertainties may be resolved in the future.

3. Justifying the precautionary principle

In this section, we argue that the PP may be justified on economic grounds. Indeed, there is an option value to developing early prevention efforts. This normative approach will permit us to clearly distinguish between the notion of precaution and that of prevention.

3.1. Option values

For a long time, economists have developed the tools to determine the appropriate course of action in dynamic settings. In particular, considerable work has been done in economic theory on the question of uncertainty and learning.

In economics, it is a widespread belief that the efficient dynamic management of risks should be different if we expect new scientific knowledge to arrive over time. A simple reason for that is irreversibility. Undertaking an irreversible action, such as the development of a wilderness area, is less valuable if one expects to obtain better information over time. Indeed, keeping a flexible position makes it possible to take advantage of the information to come (Dixit and Pindyck, 1994). Put another way, if one leaves the area undeveloped until one knows whether its development is profitable or not, then one still has the possibility of reconsidering the decision later. There is thus an *option value* to leaving the area undeveloped. Basically, the prospect of information over time biases decisions in favor of more flexibility. This well-known "irreversibility effect" (Henry, 1974) justifies the PP when preserving the environment leaves more flexibility for future choices.

However, in many situations the irreversible nature of our decisions is only one element entering the picture of environmental problems. Generally, today's actions affect future welfare not only through a reduction of the future set of choices but also directly by changing the risk borne by future generations.

Gollier, Jullien and Treich (2000) consider this broader problem. The question is to determine the optimal timing of prevention when present actions affect future risk exposure. More precisely, the authors examine the optimal level of consumption of a good which may be harmful in the future. The good's toxicity depends on its accumulated consumption over time. The level of toxicity is unknown today but scientific progress will reveal it in the future. What is the effect of scientific progress on current consumption? The authors show that this effect entails a "precautionary effect" which takes place even without any sort of irreversibility. This effect states that the prospect of receiving more precise information in the future induces less consumption today of the toxic product, as suggested by the PP. This effect works by placing a restrictive but plausible condition on the utility function of the consumer. Thus, together with the pure "irreversibility effect", this effect provides a strong normative basis to the PP when cumulative externalities and risk aversion are present.

3.2. Precaution vs. prevention

Since Knight (1921), it is usual to make a distinction between a *risk*, characterized by an objective probability distribution, and *uncertainty*, which is not related to any precise statistical estimates. For the sake of illustration, uncertainty may be thought of as a situation where the decision-maker faces a panel of experts with differing beliefs on the true probability distribution.

In such a situation, there are two sources of risk. First, there is the pure risk inherent in Nature. Basically, what is the true state of the world? Second, there is the risk in the probability distribution. This is the risk the decision-maker faces when he has to select his policy. Basically, which expert is right? Put crudely, we argue that prevention is related to the management of the first type of risk while precaution is related to the management of the second type of risk.

There is a classic difference between these two risks. Indeed, the second type of risk, which is tied to scientific uncertainty, is subject to resolution over time. With the accumulation

of knowledge, uncertainty is resolved, at least partially, allowing for a revision of beliefs. This leads to the recognition that precaution is not a static concept.

To sum up, prevention is tied to Knight's notion of risk. It is a static concept that refers to the *management of a risk* at a given time and given a stable probability distribution. On the other hand, precaution is tied to the notion of uncertainty. Precaution is a dynamic concept that recognizes scientific progress. Precaution defines *a prudent and temporary decision that aims at managing the current lack of scientific evidence.*

4. Using the Precautionary Principle for the management of global commons

In this section, we will examine the implications of the PP for the management of global pollution problems. In particular, we shall examine the optimality of precautionary policies for the climate-change problem.

4.1. Environmental degradation

The PP was initially directed at improving the management of global environmental externalities such as land or marine pollution, or more recently, climate change. One historical example of a global pollution problem is the degradation of the ozone layer. The Montreal Protocol, establishing a schedule to reduce the consumption of chlorofluorocarbons (CFCs) and halons, was signed in March 1987. Yet the scientific community knew as early as 1974, with the publication in *Nature* of the famous paper by Molina and Rowland (1974), that chlorine might destroy ozone at high altitudes. Hence, for as long as 13 years, there had been a strong inertia in the decision-making process, at least at the international level.

One can easily understand that it is politically difficult to implement early prevention measures when the underlying mechanism generating the risk is poorly known. The costs of developing early preventive actions is often very high compared to the do-nothing strategy, i.e. just waiting for better scientific evidence. For instance, in the early 1980s the American Chemical Society complained that any restriction on CFC emissions would constitute *"the first regulation to be based entirely on an unverified scientific prediction"*. The PP takes a committed stand against such arguments. It basically states that there is no sense in claiming that the environmental threat is "too uncertain" to justify costly departures from business-as-usual activities. Uncertainty should not lead to "do-nothing" strategies.

On the other hand, it is important to recognize that the Principle cannot suffice to support an alternative extreme strategy: the total suspension of the harmful activity. The appropriate strategy should thus be selected by evaluating the consequences of the various alternatives. To this end, the difficulty will be to determine the optimal balance that will account for irreversibility and for the scientific uncertainty on the distribution of future benefits. This question has recently been examined for the global-warming issue, as we will now show.

4.2. Sequential climate policy

In the issue of climate change, uncertainties are pervasive. The problem is extremely complex. Experts still do not fully understand the interactions between atmosphere, clouds, oceans and polar ice sheets. The uncertainties in climate change, the long time-scales involved, and the potentially irreversible effects has typically led policy-makers to frame the problem as a choice of either acting to reduce emissions now or waiting until we learn more about the problem.

As stated, for instance, by the IPCC or Intergovernmental Panel on Climate Change (1995): *"The choice of abatement paths involves balancing the economic risks of rapid abatement now (that premature capital stock retirement will later prove unnecessary) against the corresponding risk of delay (that more rapid reduction will then be required, necessitating premature retirement of future capital stock)"*.

The point here is that there is a tension between the rapid resolution of uncertainty and the slow entropy of the system, e.g. the climate evolves slowly compared to the rate of resolution of spatio-temporal climate models. In this context, the choice between a moderate or an aggressive reduction in emissions is determined today by the future improvement of scientific understanding of climate change and by our ability to switch to other sources of energy in the future. This has been defined as a sequential strategy for abating climate change (Hammitt, Lempert and Schlesinger, 1992).

The IPCC (1995) recognizes the efficiency of such a strategy in its summary for policy-makers: *"The challenge is not to find the best policy today for the next 100 years, but to select a prudent and flexible strategy and to adjust it over time."* At the political level, the Kyoto Protocol has been framed in the spirit of this sequential approach. For instance, the Protocol has emphasized the need to initiate early reduction of CO_2 emissions and to integrate various flexibility mechanisms. This will allow future abatement efforts to be adapted to evolving scientific knowledge.

4.3. Scientific uncertainty in macro-climatic models

The issue of global warming has triggered a large amount of economic research aiming at characterizing the optimal climate policy. This literature may be illustrated by the development of so-called "integrated assessment models". These models generally combine a Ramsey growth model with a climatic module representing the dynamics of the accumulation of greenhouse gases.

Interestingly, these "macro-climatic" models may also account for scientific uncertainty about some major parameters of climate dynamics. For instance, the panel of experts at the IPCC estimated that, for a doubling atmospheric concentration of carbon dioxide, the increase in the temperature may lie between $+1.8$°C and $+5.4$°C (IPCC, 1995). The point is that it is one thing to recognize this wide uncertainty among experts' opinions but it is another to include it within an optimization framework and to propose *one* economic-policy response.

Nordhaus (1994) derived a set of uncertain scenarios that summarize the large number of climate uncertainties. He showed that introducing expert's uncertainty increases the optimal control rate by about 50 per cent. This clearly supported the idea that environmental uncertainties matter in climate policy. This also showed the extent to which ignoring uncertainties can lead to significant policy errors.

The picture was made even more realistic by accounting for scientific progress over time. Is short-term climate policy different when one expects to learn in 2010 rather than in 2050? There is still an economic debate on this question. Some economists (Nordhaus included) argue that emissions in the current period, say 2000–2010, will have little influence on the total stock of greenhouse gases at the end of the century and that the irreversibility constraint would probably not bite in the future: damage losses are not severe enough to cut down future emissions to zero. As a result, it makes sense to delay abatement efforts at least for one decade or two. On the other hand, other economists have emphasized the importance of adjustment costs and the need for smooth adaptation. As a result, developing strong short-run abatement efforts may be optimal.

Yet we do not want to go further on the present controversy about the role of learning in climate policy. In any case, our point is that the debate on the efficacy of precautionary policies may be rationalized. It is technically feasible to amend cost–benefit analysis to respond to some "hot" debate related to the PP. However, this raises another important issue. How to implement precautionary policies?

5. Implementing the Precautionary Principle

In this section, we explain why precautionary policies may not emerge in a competitive economy or when the decision-making process is complex. The issue is then to enforce the PP to better control the potential sources of risk, such as the opportunism of some agents in situations of imperfect information. We also raise new questions inspired by the PP, such as the acceptability of the PP to the public.

5.1. Inconsistent public policies

In the last section, we have followed the tradition of public economics. We have implicitly assumed that there is a social planner who decides the optimal climate policy for society as a whole. In reality, there is not a single decision-maker but multiple decision-makers. As a result, even if precautionary policies should be adopted in the global economy, conflicting objectives and co-ordination problems among decision-makers may lead to the selection of inefficient policies.

This point is important in any global pollution problem. Indeed, pollution is a public good and no state would want to pay alone the cost of reducing global pollution. Yet, it is important to notice that uncertainty helps to reduce the extent of this problem. Basically, when one ignores which state will be affected, all states may find a mutual advantage in co-operating to reduce pollution. However, when scientific progress is expected over time, new pieces of information may reveal which country will be affected, thus making a latent free-rider problem an actual one. This is a standard Hirshleifer effect, well known in insurance theory: information destroys risk-sharing opportunities. This effect is a strong positive argument in favor of the enforcement of the Precautionary Principle at the international level. Indeed the PP may favor early co-operation among states when the free-rider problem is not present.

Another important reason for enforcing the PP is inconsistency in time. For instance, this may occur when a government is tempted to pass the burden on to its successors. Take climate negotiations: in the absence of the credibility of important sanctions at the international level, there may be a divergence between actual government commitments and future government decisions, especially if uncertainty is resolved in between. This is why several economists have stressed the need for better institutional designs and policy architecture to help the enforcement of precautionary policies.

5.2. Political opportunism under imperfect scientific knowledge

It is important to recognize that short-term regulatory policies do not generally match the political agenda of a government. Politicians in office often judge that the definite costs of short-term prevention policies dominate the potential long-term benefits those policies may generate. And, typically, opportunistic politicians may use the lack of scientific evidence to favor the delay of prevention policies. The story lines of the contaminated-blood crisis in

France or the mad-cow affair in the U.K. are authentic examples of "do-nothing" strategies, just waiting for better scientific information.

Scientific uncertainty may also generate a typical phenomenon of political demagogy. Indeed, it makes sense to think that the public is in general less well informed than politicians about some particular danger. Then, politicians with strong career concerns may prefer to select the risk policy that the public believes is good rather than the one which is actually good for the public. As a result, the influence of politics together with imperfect knowledge of the risk by the public will cause the regulator to depart from maximization of the social good.

Scientific uncertainties probably aggravate these inefficiencies. Remember that it was only after the discovery of the "ozone hole" which shocked public opinion that the Montreal Protocol was eventually signed. Before that discovery, the risk of ozone degradation was virtually unknown to the public and so partly ignored by politicians, except in countries with the highest environmental concerns (such as Germany and the Scandinavian countries).

How does one reduce political opportunism? It is customary in economics to investigate the relative economic advantages of different political systems and to select those that provide the "best" incentive schemes for politicians (Laffont and Tirole, 1993). For example, one may try to change re-election mechanisms in order to affect private benefits of government bodies. One could imagine a system that would not reappoint politicians for a second term if scientific progress revealed that they had chosen inefficient policies. Also one may facilitate the development of critical appraisals on regulatory decisions by using independent scientists to evaluate risk policies.

At a higher level, one may also investigate ways of modifying one's constitution in order to generate better incentives in risk regulatory decision-making. From this point of view, it is often said that the PP may change the rule of the game in risk politics. Indeed, it may help make politicians aware of their responsibilities in decisions taken under conditions of uncertainty. In France, for instance, in April 1993, the Conseil d'Etat gave a cautionary warning to politicians: *"In a situation of risk, one non-validated hypothesis should be taken as temporarily true, even if it is not formally demonstrated"* (translated from the French). A few years after this word of caution, several French ministers have been on trial for their respective liabilities in the contaminated-blood affair.

5.3. Should the Precautionary Principle be imposed on firms?

An important issue raised by the PP is the possibility of extending its application to firms. This issue is of crucial importance for the control of risk and the development of innovation in our society. Can we justify such an extension of the PP to firms on economic grounds?

There is an enormous literature in economics on the choice of the most efficient policy to correct production externalities. The question at stake is whether the PP may enhance efficiency by leading some polluter to better internalize potential externalities and thus to favor the development of early preventive actions. This question is particularly relevant when the firm has private information on the cost and benefits it may generate for society (Laffont and Tirole, 1993).

The answer will depend on many factors. For the sake of concreteness, take the agro-business industry producing transgenic food. A typical characteristic of this industry is that there will probably be high profits guaranteed to firms that will be able to pre-empt the market. As a result, competitive firms do not take up the option of waiting. The risk of being pre-empted by other firms would be too great. This implies that there are strong incentives to introduce innovations too soon in that industry. The question is: how to regulate this market?

One possibility is to leave this decision to the discretion of states. During the 2000 Protocol on Biosafety held in Montreal, the international community recognized the right of states to stop imports of transgenic food even if no evidence of its toxicity had been presented. The problem is that such a discretionary power may be the source of hidden protective measures by states. Hence, another possibility would be to impose the PP directly on agro-business firms, e.g. by making them liable for the damages generated if transgenic products turn out to be toxic.

There are many drawbacks to this approach as well. First, the damages may occur so far in the future that the firms may no longer exist at that date, as was the case, for instance, in the asbestos industry (Gollier, 2001). Second, it also raises the issue of the potential bankruptcy of firms, which gives rise to an *ex post* problem of victim compensation and to an *ex ante* problem of under-prevention by those causing the injury.

Another problem is that there are high set-up costs associated with the judicial process: organizing trials, proving liability, etc. A typical concern is that the legal incentives are generally more stringent for people who cause unfavorable outcomes by *acting* than for people who cause unfavorable outcomes by *not acting*. Can one really blame an entrepreneur because he has *not* sufficiently tested a product that turned out to be toxic?

This analysis can also be related to the debate on the burden of proof. As correctly noticed by Godard (2000), many observers claim that the major change introduced by the PP is the reversal of the burden of proof. Basically, a product should not be introduced until proved to be harmless by the innovator. Once again, we refuse to consider such an extreme interpretation of the PP here. It is not compatible with economic efficiency since it would potentially lead to eliminating any risky innovative activity in our society.

5.4. Risk acceptability to citizens

The discussion above has pointed out many deficiencies that may be generated by the presence of scientific uncertainty through the process of regulatory decision-making. An important issue is the need to account for the acceptability of risk policies by citizens. For example, the European Commission states that *"the scope* [of the PP] *is much broader, and includes non-economic considerations, such as the efficacy of possible options and their acceptability to the public"* (CEC, 2000). Contrary to what the Commission suggests, we do not think that this issue is independent of economic considerations.

Increasingly, the public is aware of the limits of scientific knowledge, and policy-makers have lost legitimacy in the eyes of lay people. The failures of risk-regulatory institutions have drastically reduced citizens' confidence in them. As a result, authorities have recently favored policies that may have public consent (Sinclair-Desgagné, 2001). This includes better risk-communication programs, stricter information disclosure policies by firms, product labeling, etc.

This raises an interesting question. What is the economic support for a policy that accords greater legitimacy to citizens' views of risk? First, in many situations, empowering citizen information can substantially reduce the transaction costs attributed to opportunism and administrative costs of regulation. In addition, it is often argued that such a "populist" approach to decision-making may offer a larger degree of freedom to citizens when choosing their level of risk exposure. That will permit each citizen to better adapt his response to scientific uncertainty. This is a source of welfare. Also, this approach may account for some particular characteristics of risk that may not easily be captured through a centralized decision-making process. Factors like the public's dread of the risk or aversion to ambiguity,

whether the risk is voluntary or not, natural or not, are important. They may escape a basic risk assessment analysis and the cost–benefit test. Importantly, these ideas have been recognized by the Commission (CEC, 2000): *"Decision-makers have to account for the fears generated by these perceptions and to put in place preventive measures to eliminate the risk".*

The major problem with this approach is that the public's perception of risk is subject to many cognitive biases, like the standard "availability heuristic" bias, for instance. Citizens often deem an event to be more probable when its occurrence can be easily recalled or visualized. Also, the public has a limited ability to process the information it receives. For instance, it overreacts to highly publicized risks. As a result, many rare risks (tornados, botulism, plane crashes) are perceived as more important than they really are. On the other hand, more frequent risks are underestimated by the population (automobile accidents, heart disease). Typically, public misperceptions of risk may be the result of manipulation by the media or by lobbies. For example, there are good reasons to think that genetically modified (GM) food is not a real problem – for over two decades, biotechnology has been safe and effective – but rather a weapon used by some "green" or farmers' organizations against multinationals and global corporations.

Hence, there are many arguments against a "populist" approach to risk management. Many economists argue that it would lead to the displacement or even reinforcement of market failures. The Superfund program has been proved to be inefficient. It has been said that this is because the irrationality of individuals has been embodied in government regulation (Hird, 1994). Using data on American health risk programs, Viscusi (1998) has investigated the failures of regulatory policies based on a "populist" approach as opposed to a cost–benefit or, say, a "rational" approach. The cost has been millions of dollars for the U.S., or put in another way thousands of American lives.

Of course, the right judgment probably lies between an extreme populist viewpoint and the ubiquitous rational regulator paradigm. Risk policies designed by experts and policy-makers should recognize the cognitive limitations by individuals. To this end, they could be the result of a complex process of social co-ordination among different actors (Godard, 2000).

An experiment recently developed in France is worth mentioning. In order to respond to public concerns about transgenic food, a representative panel of the population has been selected and invited to participate in seminars given by various experts (such as biologists and geneticists). Then, discussions were set up among the experts and together with the public. This gave rise to some policy recommendations provided by the public that have been seriously taken into account by policy-makers.

6. Conclusion

The Precautionary Principle (PP) provides the foundations for building a new risk-regulatory pattern. This is why it is important to understand what it means and implies. Yet it was said recently that *"no general agreement exists on what the Precautionary Principle means or how it is applied in different socioeconomic and cultural systems"* (Report of the Conference on Science and the Precautionary Principle, 2000). With the prominent literature on the PP in the social sciences in general, this paper has investigated how economics may interpret the PP and examine its implications. Let us try to sum up the main ideas we have developed:

- The PP did not introduce in national or international law the idea of environmental externality (polluter-pays principle) nor the idea of intergenerational equity (sustainable-

development principle). However, the novelty is that the PP recognizes the need to account for scientific uncertainty in environmental and health safety regulatory decision-making.

- The main goal of the PP is to encourage the prevention of a risk *before* full scientific information about this risk is available. This means that the decision process is sequential and that timing of prevention efforts is important. On normative grounds we interpret the PP as follows: does scientific uncertainty bias decisions in favor of more prevention today? We have shown that the PP may be economically justified on the grounds of irreversibility (Henry, 1974) and when risk aversion and stock externality are present (Gollier, Jullien and Treich, 2000).
- The PP does not imply the abandonment of the cost–benefit analysis paradigm; so, for example, the economic literature on climate change has examined the cost-effectiveness of early precautionary policies (Nordhaus, 1994). However, precautionary policies may not emerge spontaneously when a decision is taken by several decision-makers. The PP may then be viewed as a device to enforce early, co-operative and time-consistent policies.
- Scientific uncertainty introduces considerable room for discretion and for self-interested biases through the process of decision-making. Different social actors (politicians, experts, lobbies, entrepreneurs) may use the lack of scientific evidence to get a final decision in their own interest. The PP may then be viewed as a safeguard to reduce opportunistic behaviors in situations of asymmetric information and political constraints (Laffont and Tirole, 1993).
- The PP has introduced new questions related to risk-regulatory decision-making. It is clear, for instance, that consumer trust in regulatory institutions is of critical importance to shape risk-regulatory policies. Under conditions of considerable scientific uncertainty, cost–benefit analysis needs to account for additional constraints such as consumers' cognitive limitations or the acceptability of risk to the public.

As a final word, it may be opportune to recall that the PP is a multi-disciplinary concept, and its pure economic meaning is just one among various other meanings. Yet we have tried to show that economic science provides a pragmatic interpretation to the PP. It is satisfying *per se* since the search for a rapid consensus on the PP is consistent with its most fundamental meaning.

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